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Efficient Beam-Type Structural Modeling of Rotor Blades

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Publication date:
2015

Document Version
Peer reviewed version

Efficient Beam-Type Structural Modeling of Rotor Blades

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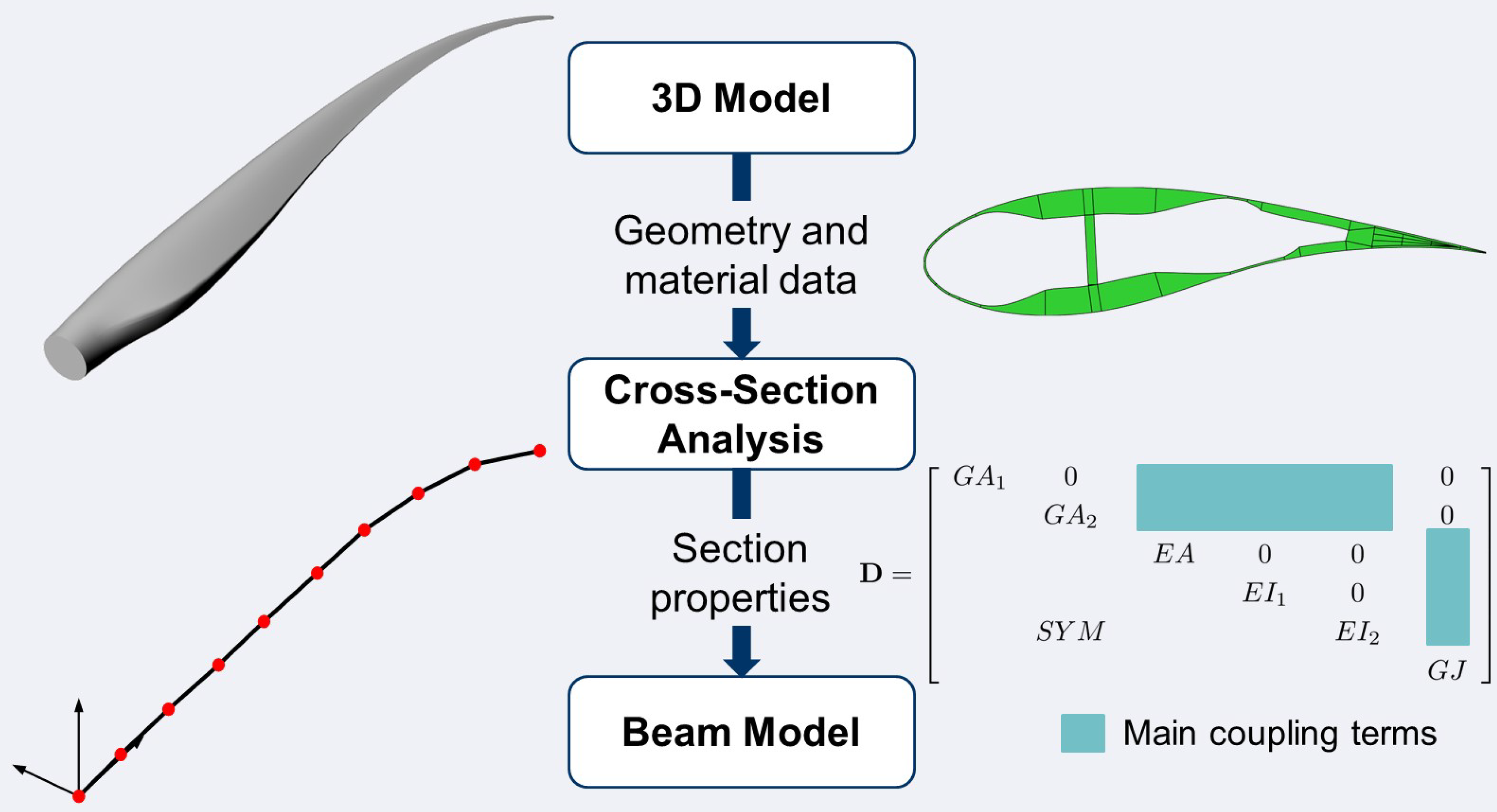
Introduction

Challenges in structural modelling of modern wind turbine blades:

- Increasing slenderness puts focus on beam theory and cross-sectional stiffness.
- Need for accurate predictions of complex behaviour, e.g. bend-torsion coupling.
- Should easily accommodate geometry and material design updates.

Structural Blade Modeling



Objective

Develop a methodology to facilitate the design of wind turbine blades using anisotropic materials and complex geometry to generate desired displacement characteristics, including bend-twist response.

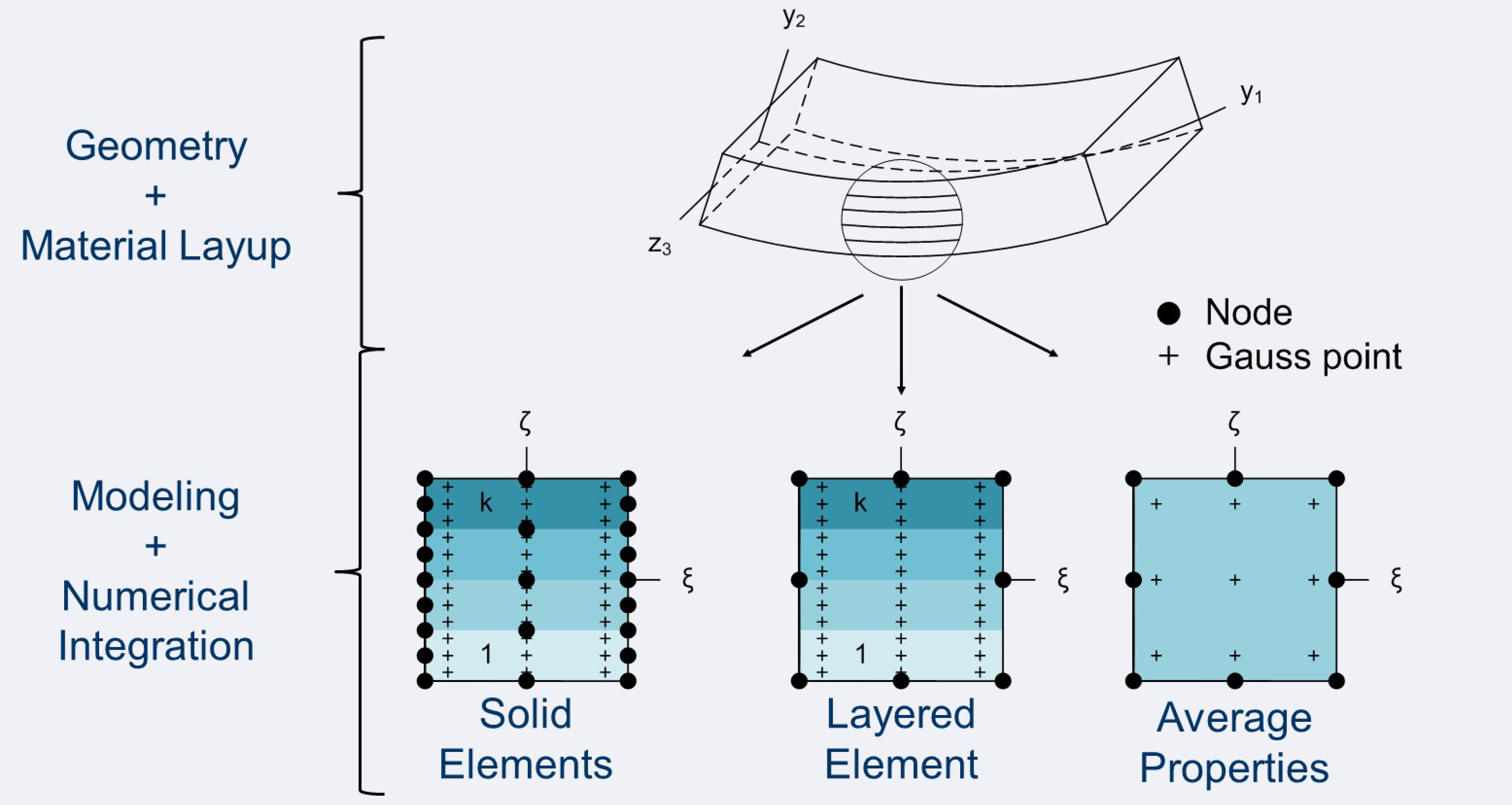
Method

Formulation of cross-section analysis for fully anisotropic materials:

Cross-section analysis tool to calculate the full six by six stiffness matrix for non-homogeneous and anisotropic sections with coupling between the deformation modes[1]. The underlying formulation is based on the stress-strain states in the classic six equilibrium modes of a beam by considering a finite thickness slice modeled by a single layer of cubic 3D finite elements.

Efficient cross-section discretization:

Finite element modelling approach based on discretizing the walls of the section using a single layer of displacement based elements whereby the element's stiffness is obtained using Gaussian quadrature through each layer[2].

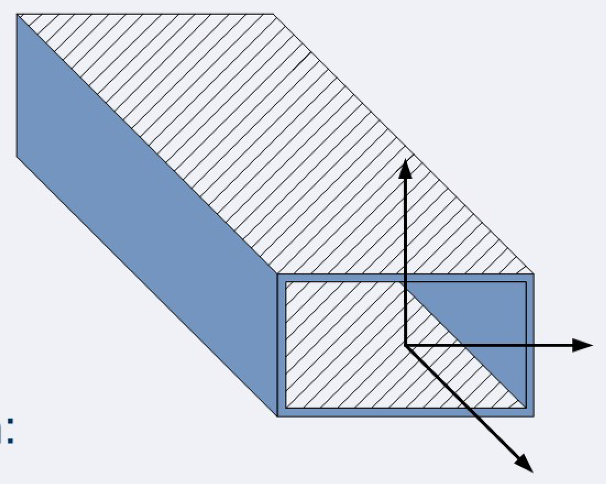


Improved beam element:

Extended beam element in which the stiffness properties are obtained via flexibility from equilibrium states that do not use assumed shape functions[3]. This so called 'complementary energy' approach immediately accepts the six by six cross-section stiffness matrices and accounts for geometry and material variations along the blade span.

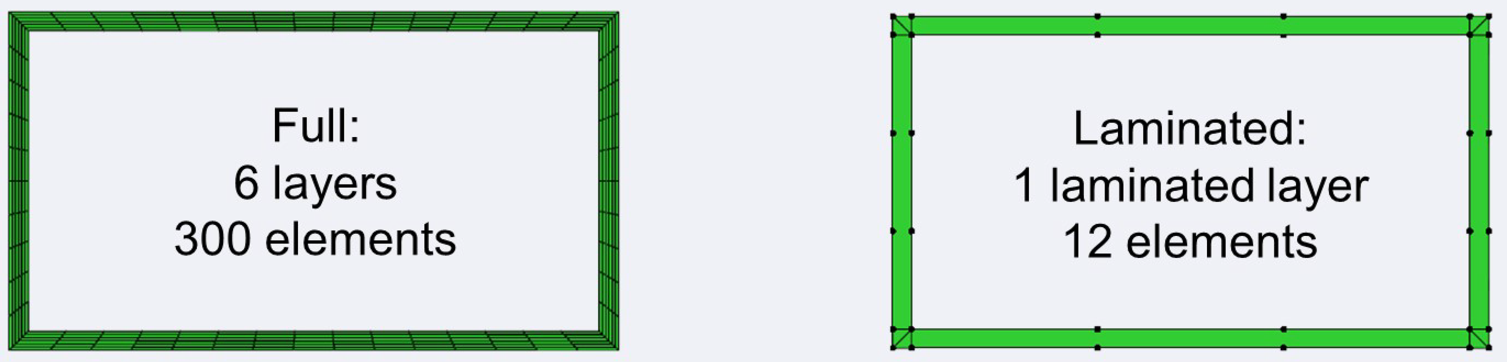
Case Study: Box Beam

Symmetric layup section with six laminas per wall exhibiting bending-torsion and extension-shear coupling.

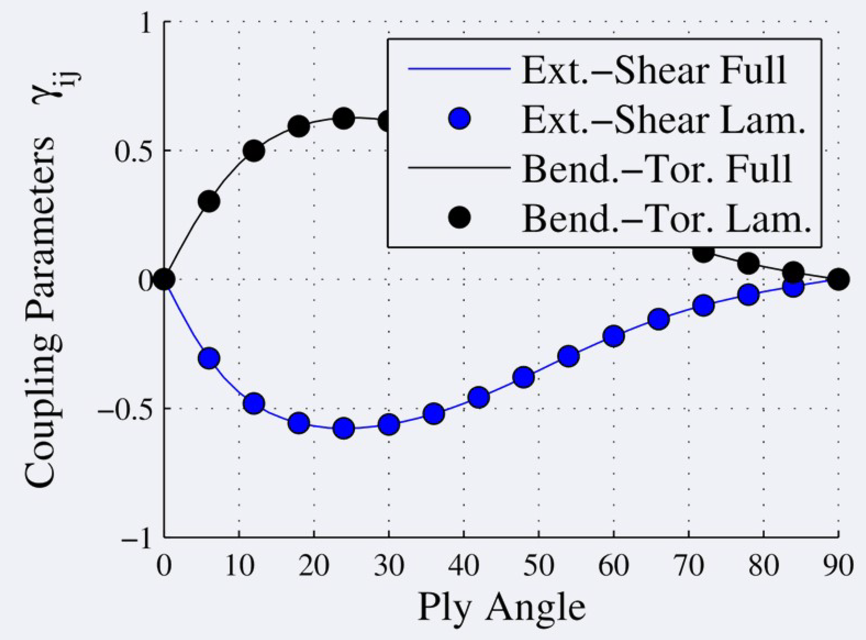


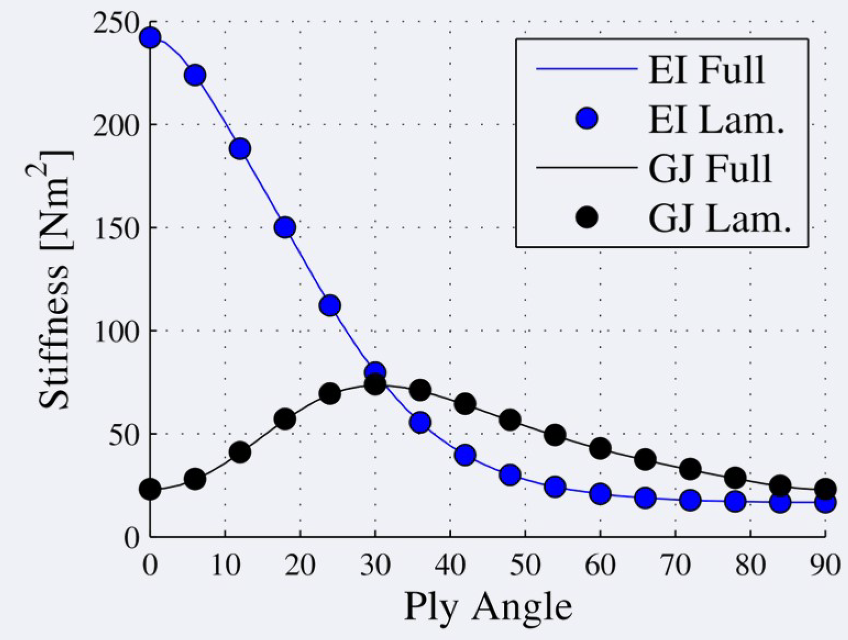
Coupling parameter: $\gamma_{ij} = \dfrac{D_{ij}}{\sqrt{D_{ii}\,D_{jj}}}$.

Conventional discretization vs. laminated approach:

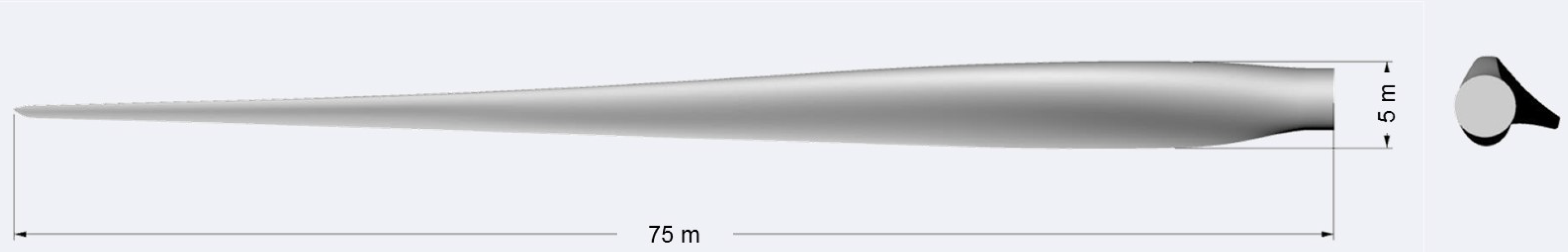


Stiffness coefficients vs. fiber angle:

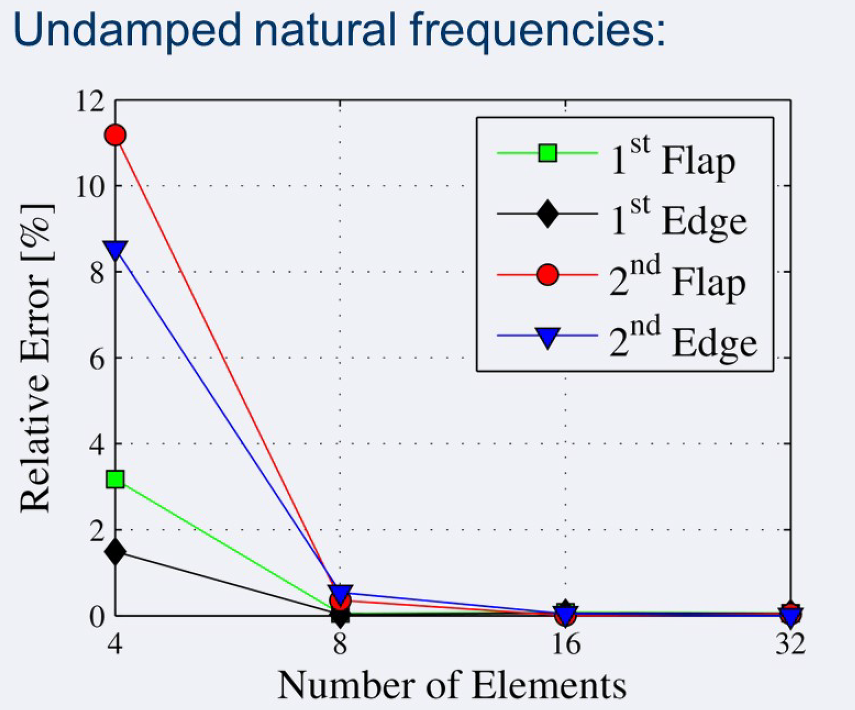




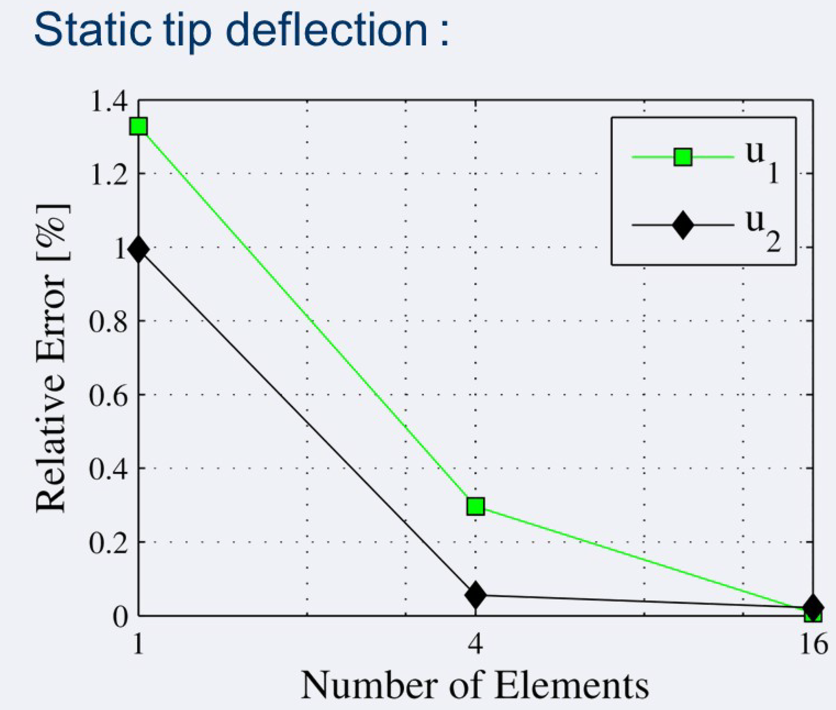
Case Study: Siemens 75 m Blade



Undamped natural frequencies:



Static tip deflection :



Conclusions

Cross-section analysis:

- Avoids special 2D theories by using cubic 3D solid elements.
- Handles thin-walled and massive parts made of general anisotropic materials.
- Provides fully coupled 6x6 stiffness matrix with limited meshing effort.

Beam element:

- Equilibrium based formulation accepting fully coupled 6x6 stiffness matrices.
- Accounts for large variations in geometry and material along the blade.
- Very few elements needed to describe dynamic and static behavior of blades.

References

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2. Couturier, P. J., Krenk, S., "Wind Turbine Cross-Sectional Stiffness Analysis using Internally Layered Solid Elements", AIAA Journal, Submitted.
3. Krenk, S., "Element Stiffness Matrix for Beams with General Cross-Section Properties," Report, Technical University of Denmark, Department of Mechanical Engineering, Denmark, 2006.